Reflective Light Modulation by Cephalopods in Shallow Nearshore Habitats

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LONG-TERM GOALS

The central question is: what are the optical principles upon which crypsis is achieved by opaque organisms in shallow, nearshore marine habitats?

OBJECTIVES

Camouflage mechanisms are not well known despite the general misconception that they are; moreover, quantification of camouflage (especially of opaque organisms) is particularly wanting. We have three objectives: (1) Acquire imagery (camouflaged animals and their backgrounds) and corresponding irradiance data from coral reef and temperate rock reef environments. (2) Perform image analyses to quantify the degree of crypsis. (3) Construct a comparative digital photographic library of shallow-water marine animals in the camouflage categories of Uniform, Mottle and Disruptive. The central focus is on octopus, cuttlefish and squid because they have the most diverse and changeable camouflage patterns known in biology. Fish and insects are studied comparatively.

APPROACH

High-resolution digital still images (Canon EOS 1Ds, Mark II camera) are acquired under completely natural marine conditions. No flash is used to avoid making artificial shadows from the flash light. A computer-controlled spectrometer (adapted for underwater use) takes downwelling and sidewelling irradiance data at the exact time of photography; then the animal reflectance data are recorded with the spectrometer (in both gross and fine detail on the animal's body) so that color- and contrast-matching can be quantified in the digital images.

WORK COMPLETED

Field work has continued well during the past 12 months. RTH completed 2 field trips (total of 37 SCUBA dives) and acquired 2,550 high-resolution digital still images of the following camouflaged species: *Octopus vulgaris*; the giant Australian cuttlefish *Sepia apama*; flounder; scorpionfish; 5 species of groupers. In addition, he was able to spend a day at the Field Museum of Chicago photographing details of insect wing patterns (77 images), with particular attention to pattern design along edges. One consequence of this is that we now have images of camouflaged animals that span

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the size of 0.5 inch moths to 3-ft long groupers. These images represent a wide diversity of body shapes, and will allow us to continue to extract the pattern features that are conserved across taxa and which, by inference, have proved through natural selection to be most successful in deceiving a wide diversity of visual predators.

Particularly noteworthy is the work accomplished in videotaping and photographing grouper camouflage on a coral reef. Some of these fish were fairly large, and provide a comparison to the cephalopod data we have been accumulating. With collaborator Professor Justin Marshall (U Queensland) and graduate student Alex Barbosa. RTH was able to obtain spectrometer data in June 2007 on giant Australian cuttlefish in all 3 basic pattern types of camouflage: uniform, mottle and disruptive. In addition, we designed and conducted a laboratory experiment in which we provided a natural substrate and used the spectrometer to measure the match of the cuttlefish pattern components to the surrounding substrate pattern components. This helped us develop a methodology of comparison that we can use as we analyze our field data on cuttlefish from Australia.

For image analyses, a portion of this year's work concentrated on edge design in disruptive camouflage patterns, using cuttlefish as the animal model to study initially. In addition, we have continued to develop a suite of methods that would be used as evaluation tools for camouflage effectiveness. This year we added six texture operators and a fourier-transform granularity energy program, both of which will complement the variogram from last year as well as some of the algorithms we use for edge detection by measuring other features of the overall pattern on the animal in relation to the background.

<u>National television.</u> Some of our research on this project was highlighted in a nationally broadcast 1-hour television program in April 2007 on PBS. The NOVA special was entitled "Kings of Camouflage" and focused on cuttlefish.

RESULTS

<u>Photography and Spectrometry *in situ*.</u> In Figure 1 is an example of how a large cuttlefish can dynamically achieve an impressive color and brightness match between components of its disruptive camouflage pattern and adjacent segments of the substrate. Two optical features are noteworthy: (i) the *curve shapes* for wavelengths (ca. 450-650nm) are matched almost perfectly; and (ii) the ranges of brightness reflectance between the animal and the sand overlap one another. Both features would render it impossible for a visual system (or an instrument) to distinguish between that light part of the animal's pattern and the light adjacent sand. The visual trick that is occurring in Disruptive coloration is that light components such as the Median mantle bar disrupt the recognizable shape of the cuttlefish, and the bar extends across the whole midsection of the animal and coincidentally merges with the white sand, further confusing the "visual integrity" of the animal; this is known as coincident disruptive coloration.

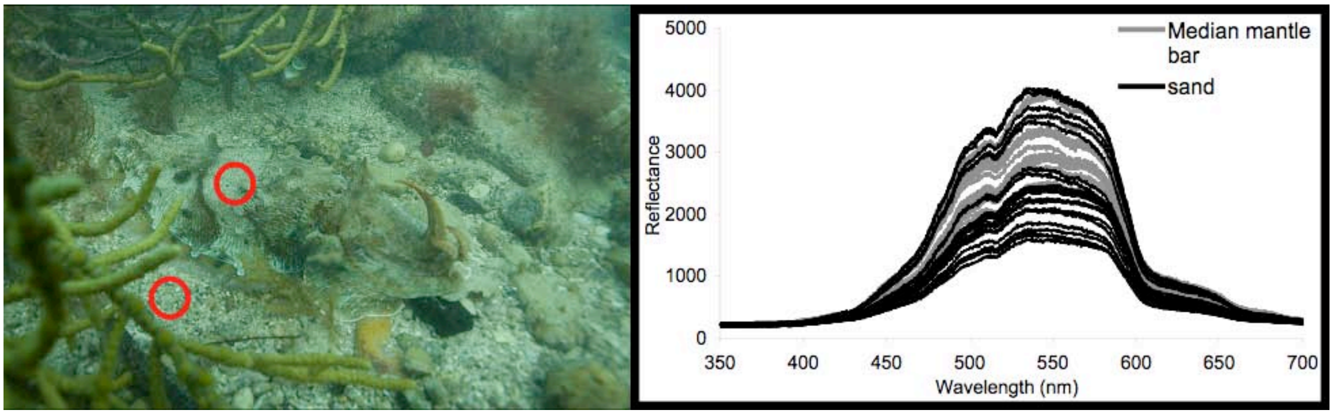


Figure 1. LEFT: A large cuttlefish (1kg) in a Disruptive camouflage pattern on a sandy/rocky bottom. The top Red Circle is a part of the "Median mantle bar" white component of the animal's Disruptive camouflage pattern, and the area in which spectrometer readings were obtained. The bottom Red Circle is a comparison area in the adjacent sand from which spectrometry data were obtained. RIGHT: Spectrometry data from the areas in the red circles. Note the remarkably similar curve shapes as well as the overlapping ranges of reflectance intensities.

Figure 2. LEFT: A well camouflaged Nassau grouper amidst stony and soft corals. RIGHT: The same grouper photographed closer to illustrate the fine details of the Disruptive coloration bands.

In Figure 2 note the effectiveness of the Disruptive camouflage pattern in a reasonably large Nassau grouper on a well developed coral reef at Little Cayman Island.

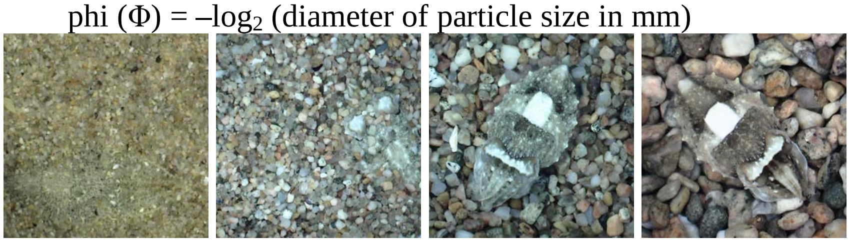
<u>Suite of image analysis methodologies to evaluate concealment.</u> We continue to develop a suite of methods for analyzing spatial properties of animals and backgrounds. Last year we developed the Variogram method (geostatistics features; characterize spatial structure based on co-variance distribution across all pixel distances) and this year we added 6 descriptors of texture (intensity, contrast, smoothness, skewness, uniformity, and entropy) based on the intensity histogram of a region. Regions of interest (ROIs) were chosen, one being a cutout of the animal, the other being a similarly shaped region in the visual background. The ROIs were also analyzed by a new (and partly proprietary) algorithm that decomposes a region into various energy bands, and describes it in terms of "granularity" or, in the parlance of our animal camouflage patterns, "mottle."

Ten animals on 4 gravels were tested; three representative images for each animal on each substrate were analyzed. Texture analysis and spectral analysis were applied for all 40 images, but variogram analysis was applied in selected images (2 images per substrate). Disruptive scores of animals were also established from an automated grading program.

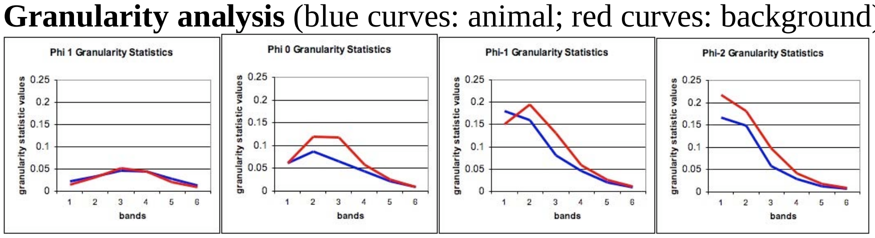
Substrate types (increase in size ->)

Φ1 Φ0 Φ-1 Φ-2

phi (Φ) = $-\log_2$ (diameter of particle size in mm)

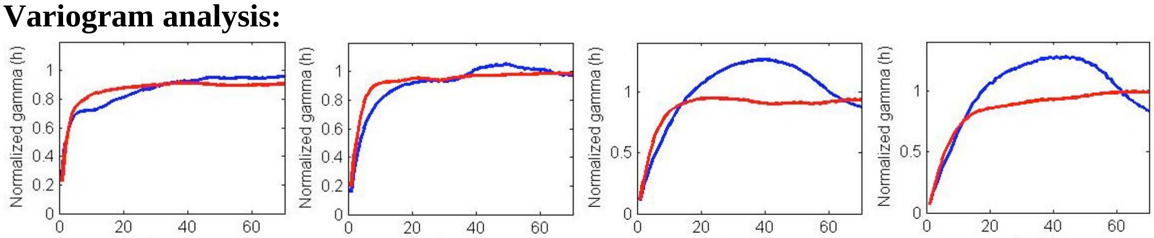


Granularity analysis (blue curves: animal; red curves: background):



The *shape* of the curve is important: the first is typical Uniform pattern curve, the second Mottle, and the last two Disruptive. Importantly, curve shapes are shared by animal and background in all.

Variogram analysis:

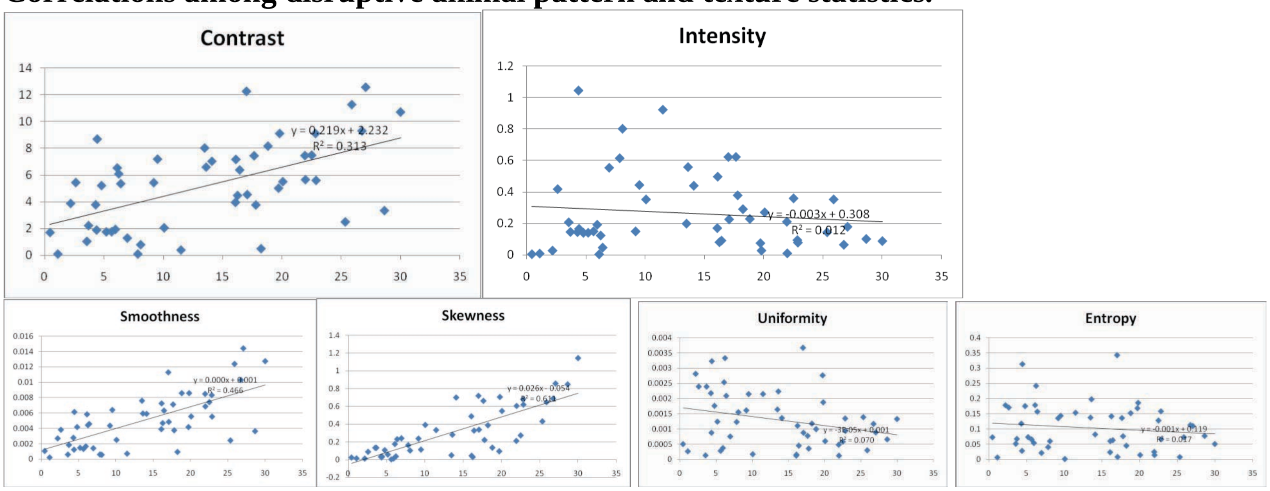


Curves coincide in Uniform and Mottle patterns (1st two graphs) but diverge in Disruptive patterns (see explanation below under Contrast discussion).

Texture analyses (1-6)

		1.Intensity	2.Contrast	3.Smoothness	4.Skewness	5.Uniformity	6.Entropy	DisruptiveScore
Φ1	Animal	117.59	21.44	0.0070	-0.0643	0.0945	5.56	1.66
	Background	124.52	21.30	0.0070	-0.0253	0.1676	5.02	
Φ0	Animal	145.71	28.77	0.0127	-0.0639	0.2281	4.83	8.55
	Background	123.29	28.43	0.0124	0.0012	0.2059	4.98	
Φ-1	Animal	143.86	36.75	0.0204	0.4467	0.1978	5.13	16.23
	Background	130.70	38.77	0.0233	0.5745	0.1993	5.15	
Φ-2	Animal	132.68	41.48	0.0258	0.9063	0.1945	5.20	28.31
	Background	135.75	39.00	0.0232	0.6425	0.1972	5.16	

Correlations among disruptive animal pattern and texture statistics.



Contrast and Intensity graphs contribute to a key issue: how exactly does Disruptive coloration work? When cuttlefish show a more disruptive pattern (i.e. higher score on x axis) the Contrast differences between the animal and the background increase. Concurrently, overall Intensity differences do not change with increased disruptiveness. This implies that disruptive body patterns do not work by general resemblance to the background (if they did, both lines would be flat as in Intensity graph). Rather, the animals deceive predator vision by increasing Contrast within its pattern components (which vary in sizes, shapes and orientations) to break up the recognizable animal (or target) shape.

The Variogram results above are suggestive of the same phenomenon.

IMPACT/APPLICATIONS

A primary lesson learned in Year 1, and supported by field work in Year 2, is how difficult it is to acquire a “full set” of light data in a camouflaged animal. Nevertheless, in 2007 we succeeded in getting excellent measurements of all 3 major camouflage pattern types in the giant cuttlefish in southern Australia.

In addition, we have obtained the first images of groupers – large teleost fishes – in each of the 3 major pattern types (uniform, mottle, disruptive) and the importance of this is that these fishes are large, and thus we can begin to test the spatial scale rules that apply to camouflage; i.e. do large creatures use the same tricks of camouflage that moderate and small animals use?

Image analyses have progressed substantially, and we have begun to assemble a suite of methods to evaluate camouflage quantitatively. Most of these programs are embedded in a MATLAB toolbox, which will be an important asset for application of the evaluation methods to a range of problems related to camouflage.

RELATED PROJECTS

The PI has two related projects sponsored by military agencies. In the past year, we have benefited from them in terms of testing a suite of methods that can be used for quantifying various aspects of camouflage. Although not reported here, this has been immensely helpful in testing novel approaches to quantifying camouflage, a subject that has received only scant attention in any of the scientific fields.

PUBLICATIONS

Two are listed, although they are not a direct outcome of the field data we are concentrating on for this grant. The first paper outlines a conceptual approach to animal camouflage and several of the thoughts were developed during field work on this ONR grant. The second paper was designed mostly as a result of our Year 1 underwater photographs of cuttlefish, and is thus connected to this effort for ONR.

Hanlon, R.T. 2007. Cephalopod dynamic camouflage. Current Biology 17 (11): R400-R405.

Mäthger,L.M., Chiao, C.C., Barbosa, A, Buresch, K., Kaye, K., Hanlon, R.T. 2007. Disruptive coloration elicited on controlled natural substrates in cuttlefish, *Sepia officinalis* J. Exp. Biol. 210: 2657-2666.